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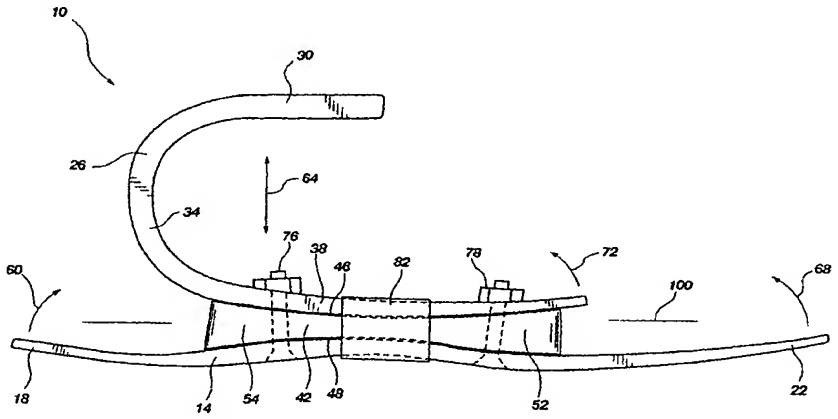
(54) Title: PROSTHETIC FOOT



(57) **Abstract:** A prosthetic foot (10) includes an energy storing, upper foot member (16) movably coupled to and spaced above an energy storing, lower foot member (14). An energy transfer medium (42) is disposed between and separates the upper and lower members. The energy transfer medium has opposite, upper and lower contact surfaces (46, 48) along which the respective upper and lower members track during flexion. The energy transfer medium had a greater flexibility than the upper and lower members to allow the upper and lower members to move with respect to one another and flex, and to provide a cushion to soften the feel of the foot while allowing the upper and lower members to be stiffer. An adjustable fastener (76, 78) may couple the energy transfer medium and upper and lower members together, to selectively tighten and loosen the upper and lower members to adjust stiffness of the foot. Separate forward and rearward energy transfer mediums (154, 158) may be movably and selectively located along a longitudinal axis of the foot to adjust stiffness. The energy transfer medium may taper from the middle (90) to the lateral side (94, 96) to allow the upper and lower members to rotate about a longitudinal axis (100) of the foot to simulate ankle rotation.

WO 02/02034 A1

PROSTHETIC FOOT

BACKGROUND OF THE INVENTION

1. The Field of the Invention.

The present invention relates generally to prosthetic feet. More particularly, the present invention relates to a prosthetic foot with stiffer members but a softer feel, adjustable stiffness, and simulated ankle rotation.

2. The Background Art.

Many individuals have lost a limb for various reasons including war, accident, or disease. In most instances these individuals are not only able to live relatively normal lives, but physically active lives as well. Often times, these individuals are aided in their everyday lives by a prosthetic limb. The objective of prosthesis is to provide an artificial limb that simulates the function and natural feel of the replaced limb.

With respect to prosthetic feet, the development of a functional and natural artificial foot has been limited only by material and imagination. Many designs have attempted to copy the anatomy of the foot or simulate its actions by replacing the bones and muscle with various mechanical components. Other designs have departed radically from mere anatomical copying or mechanical simulation by replacing the entire foot with an energy storage element such as a spring. As the user steps onto the foot, the user's weight compresses the spring. As the user moves forward, the user's weight comes off the foot and the energy stored in the spring is used to propel the user forward. Examples of such energy storing, spring-like feet include U.S. Patents 5,037,444; 4,547,913; 5,181,932 and 5,976,191.

The prosthetic feet typically include spring-like members which are typically flexible and resilient. In order to provide a natural feel and cushion of a natural foot, the members must be flexible and deflect under the user's weight. Such flexibility and the ability to deflect often require the members forming the foot to be structurally weak, or more flexible. On the other hand, it is desirable to make the members as strong or stiff as possible from a structural and

durability standpoint. Thus, there may be a trade-off between obtaining a sufficient cushion or feel, with members that are weak or flexible and over-deflect, and obtaining a solid and durable structural foot, with stiffer members.

The stiffness of prosthetic feet typically vary according to the intended use. Feet intended for everyday use typically require a soft feel and thus incorporate a loose spring. Feet intended for athletic use typically require strength and thus incorporate a stiff spring. Feet designed for particular purposes are typically unsuited for other purposes. Stiff, athletic feet are too hard for everyday use, and loose, everyday feet are too fragile for athletic use. Multiple-use feet have been designed which are capable of many different uses, but without being particularly well suited for any specialized use.

In addition, users may have different weights. Thus, prosthetic feet may require a high degree of custom design, or be particularly tailored to the individual user. However, it is desirable from a cost and manufacturing standpoint to create a foot which is usable by many sizes of individuals.

Furthermore, most prosthetic feet tend to focus on the major aspect of the foot in storing and returning energy. Thus, many prosthetic feet ignore other aspects provided by a natural foot, such as lateral ankle rotation or pivoting, or inversion and eversion, and toe rotation.

SUMMARY OF THE INVENTION

It has been recognized that it would be advantageous to develop a prosthetic foot with stiffer or stronger members for durability, while maintaining a softer, cushioned, more natural feel. In addition, it has been recognized that it would be advantageous to develop a prosthetic foot with adjustable stiffness for accommodating different uses or different users. In addition, it has been recognized that it would be advantageous to develop a prosthetic foot which simulates ankle rotation. In addition, it has been recognized that it would be advantageous to develop a prosthetic foot which simulates toe rotation.

The invention provides a prosthetic foot with stiffer members but a softer feel, adjustable stiffness, and simulated ankle rotation. Thus, the foot combines

the opposing properties of stiffness and softness. The prosthetic foot includes upper and lower energy storing feet members which are formed of a flexible and resilient material which stores energy when flexed. The lower foot member or sole member is substantially flat, and extends from a heel portion to a toe portion. The upper foot member or forefoot member is movably coupled to and spaced above the upper foot member. The upper foot member extends from an attachment portion which is configured for attachment to a stump of an amputee, through an arcuate portion, and to a coupling portion coupled to the lower foot member.

An energy transfer medium advantageously is disposed between and separates the upper and lower foot members. The energy transfer medium advantageously has a greater flexibility than the upper and lower foot members to allow the upper and lower foot members to move with respect to one another and flex. Preferably, the energy transfer medium has opposite, upper and lower contact surfaces along which the respective upper and lower foot members track during flexion. Alternatively, the energy transfer medium may have opposite, parallel upper and lower contact surfaces. Thus, the energy transfer medium provides a cushion to soften the response of the foot, while allowing the upper and lower foot members to be stiffer.

In accordance with one aspect of the present invention, an adjustable fastener may couple the energy transfer medium and upper and lower foot members together, and selectively tightens and loosens the upper and lower foot members to adjust stiffness of the foot.

In accordance with another aspect of the present invention, the energy transfer medium may include a continuous member with a double wedge configuration. A forward wedge shape may be disposed in a forward location, and a rearward wedge shape may be disposed in a rearward location. The forward and rearward wedge shapes taper towards one another.

In accordance with another aspect of the present invention, the energy transfer medium may taper from a middle to a lateral side, such that the side is

thinner than the middle. The taper allows the upper and lower foot members to rotate or pivot about a longitudinal axis of the foot to simulate ankle rotation.

In accordance with another aspect of the present invention, the energy transfer medium may have a stiffness which varies along a longitudinal direction.

In accordance with another aspect of the present invention, the energy transfer medium may include separate forward and rearward mediums which are movably disposed in respective forward and rearward locations. Thus, the mediums may be selectively located along the longitudinal axis of the foot to adjust stiffness. Slots may be formed in the upper and lower foot members to movably receive the fasteners and to selectively locate the mediums along the longitudinal axis of the foot. A plurality of holes may be formed in the upper and lower foot members to receive the fasteners, and to selectively locate the mediums along the longitudinal axis of the foot.

In accordance with another aspect of the present invention, the energy transfer medium may include separate forward and rearward mediums which have different stiffnesses.

In accordance with another aspect of the present invention, a pivot joint may pivotally connect the upper and lower foot members.

In accordance with another aspect of the present invention, a secondary upper foot member may extend from the attachment location to the heel location. A secondary energy transfer medium may be located between the secondary upper foot member and the lower foot member.

In accordance with another aspect of the present invention, the upper and lower foot members each may be split into first and second foot members to simulate toe rotation.

In accordance with another aspect of the present invention, the upper foot member may be directly coupled to and disposed on the lower foot member. The energy transfer medium may be disposed on the upper foot member and coupled to the upper and lower foot members. A clip may couple the energy transfer medium to the upper and lower foot members. An

adjustment member may be coupled to the clip and bearing against the energy transfer medium to selectively tighten and loosen the upper and lower foot members to adjust stiffness of the foot.

Additional features and advantages of the invention will be set forth in the detailed description which follows, taken in conjunction with the accompanying drawing, which together illustrate by way of example, the features of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a side view of a prosthetic foot in accordance with the present invention;

FIGs. 2a-2d are rear views of other prosthetic feet in accordance with the present invention;

FIG. 3 is a side view of another prosthetic foot in accordance with the present invention;

FIG. 4 is a top view of the prosthetic foot of FIG. 3a;

FIG. 5 is a side view of another prosthetic foot in accordance with the present invention;

FIG. 6 is a side view of another prosthetic foot in accordance with the present invention;

FIG. 7 is a side view of another prosthetic foot in accordance with the present invention;

FIG. 8 is a side view of another prosthetic foot in accordance with the present invention;

FIG. 9 is a graph showing force versus deflection of prosthetic feet in accordance with the present invention as compared to some prior art feet;

FIG. 10 is a top view of another prosthetic foot in accordance with the present invention; and

FIG. 11 is a rear view of the prosthetic feet of FIG. 10.

DETAILED DESCRIPTION

For the purposes of promoting an understanding of the principles of the invention, reference will now be made to the exemplary embodiments illustrated in the drawings, and specific language will be used to describe the same. It will nevertheless be understood that no limitation of the scope of the invention is thereby intended. Any alterations and further modifications of the inventive features illustrated herein, and any additional applications of the principles of the invention as illustrated herein, which would occur to one skilled in the relevant art and having possession of this disclosure, are to be considered within the scope of the invention.

As illustrated in FIG. 1, a prosthetic foot 10 of the present invention is shown. The prosthetic foot 10 advantageously includes a full length sole or lower foot member 14 which extends from a heel portion 18 to a toe portion 22. It is believed that the full length lower foot member 14 provides a smoother gait. In addition, the prosthetic foot 10 includes a forefoot or upper foot member 26 which extends from an attachment portion 30, which is coupled to a stump of an amputee, through an arcuate portion 34, to a coupling section 38, which is coupled to the lower foot member 14.

The attachment portion 30 may attach to a socket (not shown) for receiving the stump of the amputee. The socket is configured for the specific needs of the amputee but typically has a portion adapted for standard attachment. The attachment portion 30 of the upper foot member 26 may be attached to the socket by any means, such as by nut and bolt. As shown in FIG. 1, the upper foot member 26 may be curved in a C-shape, with the socket attaching to the top of the attachment portion 30. Alternatively, as shown in FIG. 3, an upper foot member 40 may be curved in an L-shape, with the socket attaching to the side of the attachment portion 30.

The heel portion 18 is located at a heel location in a region near the rear of the foot 10 where the heel of a natural foot would be located. Similarly, the toe portion 22 is located at a toe location in a region near the front of the foot 10 where the toes of a natural foot would be located.

The lower and upper foot members 14 and 26 are energy storing foot members which deflect or flex, storing energy, much like a leaf spring. Thus, the upper and lower foot members 26 and 14 are formed of a flexible and resilient material which allows the foot members 14 and 26 to deflect or flex. Preferably, the foot members are formed of a fiber reinforced resin material, such as a graphite reinforced resin.

The upper foot member 26 is disposed above, and spaced from, the lower foot member 14, such that the foot members 14 and 26 are in a non-contacting relationship, or are not directly coupled. An energy transfer medium 42 advantageously is disposed between, and separates, the foot members 14 and 26. The energy transfer medium 42 preferably is more flexible than the energy storing foot members 14 and 26, and allows the foot members 14 and 26 to move with respect to one another. In addition, the energy transfer medium 42 allows the foot members 14 and 26 to deflect or flex, and advantageously allows a greater range of motion of the foot members 14 and 26. Thus, the energy transfer medium 42 provides a cushioned, softer, and less stiff feel to the foot 10, making the foot 10 more comfortable and natural. The addition of the energy transfer medium 42 also advantageously allows the foot members 14 and 26 to be stiffer and stronger, while still providing a softer, cushioned feel. Thus, the stiffer stronger foot members 14 and 26 may be more durable.

The energy transfer medium 42 may include a rubber or urethane, and may have a specified stiffness or hardness, such as a durometer value. The stiffness or hardness of the energy transfer medium 42 may be consistent throughout the medium 42. Alternatively, the stiffness or hardness of the medium 42 may vary throughout the medium 42. For example, the stiffness or hardness of the medium 42 may vary along the length thereof, such as softer or more flexible at the distal ends, and increasing in stiffness or harness towards the middle. Such a configuration may allow a softer initial response of the foot, while providing a greater subsequent force response.

In addition, the energy transfer medium 42 allows the foot members 14 and 26 to move or pivot with respect to one another as the user steps on, or

walks with, the foot 10. Thus, the foot 10 may more closely mimic the movement and feel of a real foot.

The energy transfer medium 42 has opposite, upper and lower contact surfaces 46 and 48 which contact the respective upper and lower foot members 26 and 14. The upper and lower surfaces 46 and 48 may be non-parallel, as shown in FIG. 1, or parallel, as shown in FIG. 7, and form surfaces along which the upper and lower foot members 26 and 14 may track during deflection or flexion. As the foot members 14 and 26 move and flex, they bear against the surface contours of the energy transfer medium 42. Thus, the shape of the energy transfer medium 42 guides the movement and flexation of the foot members 14 and 26.

In addition, the energy transfer medium 42 may be a single, continuous member with a double wedge, or hourglass, configuration. A forward wedge-shaped portion 52 is disposed in a forward location, while a rearward wedge-shaped portion 54 is disposed in a rearward location. The wedge-shaped portions 52 and 54 extend from thicker outer ends, and taper towards one another to a thinner middle portion where they join. The upper and lower surfaces 46 and 48 may be broadly curved to conform to and/or maintain the shape of the upper and lower foot members 26 and 14.

As the user steps on the prosthetic foot 10, an applied force, such as the user's weight, causes the heel portion 18 of the lower foot member 14 to deflect, as indicated by arrow 60. In addition, the upper foot member 26 deflects, indicated by arrow 64. The energy transfer medium 42 allows the heel portion 18 to deflect and/or move with respect to the upper foot member 26, providing a soft, cushioned feel. As stated above, the upper and lower foot members 26 and 14 are stiffer and stronger, and thus deflect or flex less. The energy transfer medium 42, however, is flexible, and deflects or compresses, allowing the foot 10 to have a soft, flexible feel.

As the user continues to step, or walk, on the foot 10, the toe portion 22 deflects, indicated by arrow 68. In addition, the upper foot member 26 deflects, indicated by arrow 72. Again the energy transfer medium 42 allows the toe

portion 22 to deflect and/or move with respect to the upper foot member 26, while the energy transfer medium 42 deflects or compresses.

Because the foot members 14 and 26 are made of a resilient material, the foot members 14 and 26 act as springs and store the energy to be subsequently released. As the user lifts the foot 10, the toe portion 22 of the foot 10 returns to its original position, pushing-off.

Fasteners 76 and 78 couple the energy transfer medium 42 and the upper and lower foot members 26 and 14 together. A rear fastener 76 couples the rearward wedge-shape portion 54, while a forward fastener 78 couples the forward wedge-shape portion 52. Preferably, the fasteners 76 and 78 are adjustable fasteners to selectively loosen and tighten the foot members 14 and 26 together. Loosening and tightening the foot members 14 and 26, expands and compresses the energy transfer medium 42, thus advantageously adjusting the stiffness of the foot 10. For example, tightening the fasteners 76 and/or 78 pre-compressed or pre-deflects the energy transfer medium 42, reducing the amount of compression or deflection as the user steps on the foot 10, and providing a stiffer feel. Providing two fasteners, or forward and rearward fasteners 76 and 78, allows the heel and/or toe of the foot 10 to be selectively adjusted. For example, either the heel or toe may be adjusted independently of the other by loosening or tightening the forward or rearward fasteners 76 and 78. The fasteners 76 and 78 may include a threaded bolt or screw passing through the foot members 14 and 26 and the medium 42, and a nut threaded on the bolt or screw.

In addition, the foot members 14 and 26 may be wound with resin impregnated fiber 82 to couple the foot members together.

As described above, the energy transfer medium 42 may be shaped or contoured in a longitudinal direction to control the deflection characteristics of the upper and lower foot members 26 and 14, and the performance of the foot 10. The energy transfer medium 42 advantageously may be further contoured in a lateral direction to provide for lateral rotation or pivoting, to simulate ankle rotation, or inversion and eversion movement.

Referring to FIGs. 2a-2c, the energy transfer medium has a middle 90 and lateral sides 94 and 96. The medium advantageously tapers from the middle 90 to the lateral sides 94 and 96 such that the sides 94 and 96 are thinner than the middle 90, and at least one of the upper or lower surfaces of the medium advantageously are contoured or curved to allow the upper and lower foot members 26 and 14 to rotate or pivot about a longitudinal axis 100 of the foot 10, simulating ankle rotation.

Referring to FIG. 2a, an energy transfer medium 104 has an upper surface 108 and rounded upper edges 112 and 114 between the upper surface 108 and the lateral sides 94 and 96. Thus, the upper foot member 26 may rotate or pivot, as indicated by arrow 118, about the longitudinal axis 100. As the upper foot member 26 rotates, it tracks along the contoured upper surface 108 of the energy transfer medium 104.

Referring to FIG. 2b, an energy transfer medium 122 has a lower surface 126 and rounded lower edges 130 and 132 between the lower surface 126 and the lateral sides 94 and 96. Thus, the lower foot member 14 may rotate or pivot, as indicated by arrow 136, about the longitudinal axis 100. As the lower foot member 14 rotates, it tracks along the contoured lower surface 126 of the energy transfer medium 122.

Referring to FIG. 2c, an energy transfer medium 140 has both upper and lower surfaces 108 and 126 which are contoured so that both the upper and lower foot members 26 and 14 rotate or pivot, as indicated by arrow 144, about the longitudinal axis 100.

Referring to FIG. 2d, an energy transfer medium 145 alternatively may taper inwardly from the sides to the middle, such that the medium has thicker sides 146 and a thinner middle 147. The upper and/or lower surfaces 148 and 149 may be concave. Such a configuration may be utilized to alter the performance characteristics of the foot, such as to stiffen ankle rotation.

As discussed above, the fasteners 76 and 78 may be loosened or tightened to adjust the stiffness of the energy transfer medium, and thus adjust the stiffness of the foot. In addition, the energy transfer medium may have a

constant hardness, or a hardness that varies along its length. Furthermore, the energy transfer medium advantageously may be selectively and movably located between the upper and lower foot members 26 and 14 to adjust the performance characteristics of the foot members 14 and 26, and thus the performance of the foot.

Referring to FIG. 3, a prosthetic foot 150 may have two separate energy transfer mediums, such as forward and rearward energy transfer mediums 154 and 158 located at forward and rearward locations. The forward and rearward energy transfer mediums 154 and 158 may be similar to the above described energy transfer medium, but separate from one another. Thus, the mediums 154 and 158 may be contoured, or have a wedge shape.

The forward and rearward mediums 154 and 158 advantageously are selectively and movably located along the longitudinal axis 100 to adjust the stiffness of the foot 150. The rearward medium 158 may be moved forward and backward, as indicated by arrow 162. Moving the rearward medium 158 forward allows the heel portion 18 of the lower foot member 14 a greater range of deflection, providing a softer feel. In addition, moving the medium 158 forward extends the effective length of the heel portion 18, creating a longer lever arm which increases the force on the medium 158. Moving the rearward medium 158 backward restricts the range of deflection of the heel portion 18, providing a stiffer feel.

Similarly, the forward medium 154 may be moved forward and backward, as indicated by arrow 164. Moving the forward medium 154 forward restricts the range of deflection of the toe portion 22, providing a stiffer feel. Moving the medium 154 backward allows the toe portion 22 a greater range of deflection, providing a softer feel.

Selectively adjusting the location of the energy transfer mediums 154 and 158 may be accomplished in several ways, such as by providing slots or a plurality of holes in the foot members 14 and 26 to selectively locate the fasteners 76 and 78, and thus the mediums 154 and 158. Referring to FIG. 4, slots, represented by slot 162, advantageously may be formed in the upper and

lower foot members, with the fasteners, represented by fastener 78, movably disposed in the slots. The fastener 78 may be moved forward or backward within the slot 162 to selectively locate the energy transfer medium 154 along the longitudinal axis 100.

Alternatively, a plurality of holes, represented by holes 166, may be formed in the upper and lower foot members, with the fasteners, represented by fastener 76, selectively located in the holes. The fastener 76 may be moved forward or backward within the holes 166 to selectively locate the energy transfer medium 158 along the longitudinal axis 100. It is of course understood that either medium 154 and 158 may be selectively located using either holes or slots.

In addition, each of the forward and rearward energy transfer mediums 154 and 158 may have a different stiffness. Thus, the characteristics or properties of the foot may be customized or tailored to the individual user or use.

Referring to FIG. 5, a prosthetic foot 170 advantageously may have the upper and lower foot members 26 and 14 pivotally hinged together by a pivot joint 174. First, upper flanges 178 may extend from the upper foot member 26, while second, lower flanges 182 extend from the lower foot member 14. A pivot pin 186 passes through the flanges 178 and 182 forming a pivot point about which the foot members 14 and 26 pivot, indicated by arrows 190 and 194. Referring to FIG. 6, an alternative embodiment of a prosthetic foot 200 is shown in which the upper and lower foot members 26 and 14 are directly coupled together such that they abut one another, or with an upper surface of the lower member 14 contacting a lower surface of the upper member 26. In addition, energy transfer mediums 204 and 208 are disposed on top of the upper member 26. A pair of clips are disposed around the foot members 14 and 26, such as rearward and forward clips 212 and 216 disposed at respective forward and rearward locations. The clips 212 and 216 have a gap or space formed between an upper portion of the clips 212 and 216 and an upper surface of the upper foot member 26. The energy transfer mediums 204 and 208 are disposed

in the gaps or spaces of the respective clips 212 and 216. Adjustment members, such as screws 220 and 224 may be disposed at the upper portion of the clips 212 and 216 to bear against the energy transfer mediums 204 and 208 to adjust the stiffness of the foot 200.

The energy transfer mediums 204 and 208 advantageously allow the upper foot member 26 to move and/or deflect within the clips 212 and 216, and thus move and/or deflect with respect to the lower foot member 14. Again, the energy transfer mediums 204 and 208 advantageously provide a softer, cushioned feel, and allow the foot members 14 and 26 to be stiffer.

Referring to FIG. 7, a prosthetic foot 230, similar in many respects to the feet described above with respect to FIGs. 1 and 3, may have a lower foot member 232 with a flat upper surface 234, and an upper foot member 236 with a flat lower member 238. The foot members 232 and 236 may be oriented so that the surfaces 234 and 236 are substantially parallel. The foot 230 also may have one or more energy transfer mediums, such as forward and rearward energy transfer mediums 240 and 242 located at forward and rearward locations. The forward and rearward energy transfer mediums 240 and 242 may be similar to the above described energy transfer medium, but have opposite, parallel upper and lower surfaces 244 and 246. Thus, the mediums 240 and 242 may be more easily adjusted or moved along the longitudinal axis 100.

Referring to FIG. 8, a prosthetic foot 250 advantageously may have a secondary upper foot member 254 which extends from an attachment portion 258, for attachment to a stump of an amputee, through an arcuate section 262, and to a heel section 266. The attachment portion 258 may be located at the attachment section of the upper foot member. The heel section 266 is located above, and separate from, the heel portion 18 of the lower foot member 14. An energy transfer medium 270 advantageously may be disposed between the heel portions 18 and 266 of the lower foot member 14 and secondary upper foot member 254. Again, the structure and function of the energy transfer medium 270 are similar to those described above.

Referring to FIG. 9, a graph 300 demonstrates the performance of the above described feet with respect to some typical prior art feet, represented by dashed line 304. The graph 300 demonstrates the force, along the y-axis, with respect to deflection, along the x-axis. The feet of the present invention may be loosened so that the energy transfer medium provides a softer feel, represented by line 308. It will be noted that the response of the feet is initially soft, or requires lesser force to deflect the foot members. In addition, the feet may be subsequently stiffer, requiring greater force to deflect the foot members, as represented by line 312. In addition, the feet may be tightened to stiffen the feet, represented by line 316. Thus, the feet require a greater force to deflect the foot members over the entire range.

Referring to FIGs. 10 and 11, a prosthetic foot 350, similar in many respects to those described above, advantageously may be split to simulate toe rotation. Thus, the sole or lower foot member 354 may be include a gap extending from the toe portion towards the heel portion to partially or fully split first and second lower foot members 358 and 360. The first and second members are disposed adjacent one another and independently movable and/or capable of deflection with respect to one another. Similarly, the forefoot or upper foot member 364 may be partially of fully split into first and second upper foot members 368 and 370 disposed adjacent one another and independently movable and/or capable of deflection with respect to one another. The energy transfer medium may include first and second rearward mediums 374 and 376, and first and second forward mediums 380 and 382.

The first and second upper foot members 368 and 370, as well as the first and second lower foot members 358 and 360, are disposed adjacent one another with a space or gap separating them, and are independently movable with respect to each other. The upper and lower foot members may be mirror images of one another, or may be configured to resemble an actual foot.

Because the foot 350 advantageously may be composed of two upper foot members 368 and 370, and two lower foot members 358 and 360, the foot 350 is able to respond to uneven terrain more like a natural foot with rotating

toes. In addition, the foot 350 is better able to simulate toe and axial foot rotation. Furthermore, first and second foot members of either the upper and/or lower foot members may have different spring forces, or stiffness, to better simulate a natural foot.

It is to be understood that the above-described arrangements are only illustrative of the application of the principles of the present invention. Numerous modifications and alternative arrangements may be devised by those skilled in the art without departing from the spirit and scope of the present invention and the appended claims are intended to cover such modifications and arrangements. Thus, while the present invention has been shown in the drawings and fully described above with particularity and detail in connection with what is presently deemed to be the most practical and preferred embodiment(s) of the invention, it will be apparent to those of ordinary skill in the art that numerous modifications, including, but not limited to, variations in size, materials, shape, form, function and manner of operation, assembly and use may be made, without departing from the principles and concepts of the invention as set forth in the claims.

CLAIMS

What is claimed is:

1. A prosthetic foot, comprising:

a substantially flat, energy storing, lower foot member formed of a flexible and resilient material which stores energy when flexed, the lower foot member extending from a heel portion to a toe portion;

an energy storing, upper foot member, movably coupled to and spaced above the lower foot member, formed of a flexible and resilient material which stores energy when flexed, the upper foot member extending from an attachment portion which is configured for attachment to a stump of an amputee, through an arcuate portion, and to a coupling portion coupled to the lower foot member;

an energy transfer medium, disposed between and separating the upper and lower foot members, having opposite, upper and lower contact surfaces along which the respective upper and lower foot members track during flexion; and

an adjustable fastener, coupling the energy transfer medium and upper and lower foot members together, to selectively tighten and loosen the upper and lower foot members to adjust stiffness of the foot.

2. A prosthetic foot in accordance with claim 1, wherein the energy transfer medium has a greater flexibility than the upper and lower foot members to allow the upper and lower foot members to move with respect to one another and flex, and to provide a cushion to soften the response of the foot while allowing the upper and lower foot members to be stiffer.

3. A prosthetic foot in accordance with claim 1, wherein the energy transfer medium includes a continuous member with a double wedge configuration including a forward wedge shape disposed in a forward location and a rearward wedge shape disposed in a rearward location, the forward and rearward wedge shapes tapering towards one another.

4. A prosthetic foot in accordance with claim 1, wherein the energy transfer medium includes a middle portion and a lateral side, and wherein the energy transfer medium tapers from the middle portion to the lateral side such that the side is thinner than the middle portion to allow the upper and lower foot members to rotate about a longitudinal axis of the foot to simulate ankle rotation.

5. A prosthetic foot in accordance with claim 1, wherein the energy transfer medium is removably coupled to the upper and lower foot members such that various different energy transfer mediums with different stiffnesses may be substituted.

6. A prosthetic foot in accordance with claim 1, wherein the energy transfer medium has a stiffness which varies along a longitudinal direction.

7. A prosthetic foot in accordance with claim 1, wherein the energy transfer medium includes separate forward and rearward mediums movably disposed in respective forward and rearward locations to be selectively located along the longitudinal axis of the foot to adjust stiffness.

8. A prosthetic foot in accordance with claim 7, further comprising slots formed in the upper and lower foot members; and wherein the adjustable fasteners are movably disposed in the slots to selectively locate the mediums along the longitudinal axis of the foot.

9. A prosthetic foot in accordance with claim 7, further comprising a plurality of holes formed in the upper and lower foot members to receive the fasteners, and wherein the fasteners may be selectively located in the holes to selectively locate the mediums along the longitudinal axis of the foot.

10. A prosthetic foot in accordance with claim 1, wherein the energy transfer medium includes separate forward and rearward mediums disposed in respective forward and rearward locations, and each of the forward and rearward mediums having a different stiffness.

11. A prosthetic foot in accordance with claim 1, further comprising;

a pivot joint pivotally connecting the upper and lower foot members and having a pivot point about which the upper and lower foot members pivot with respect to one another.

12. A prosthetic foot in accordance with claim 1, further comprising:

a secondary upper foot member, extending from the attachment location to the heel location; and

a secondary energy transfer medium, located between the secondary upper foot member and the lower foot member.

13. A prosthetic foot in accordance with claim 1, wherein the upper and lower foot members include a gap extending from the heel portion to the toe portion to split the upper and lower foot members into first and second foot members to simulate toe rotation.

14. A prosthetic foot, comprising:

a substantially flat, energy storing, lower foot member formed of a flexible and resilient material which stores energy when flexed, the lower foot member extending from a heel portion to a toe portion;

an energy storing, upper foot member, movably coupled to and spaced above the lower foot member, formed of a flexible and resilient material which stores energy when flexed, the upper foot member extending from an attachment portion which is configured for attachment to a stump of an amputee, through an arcuate portion, and to a coupling portion coupled to the lower foot member;

an energy transfer medium, disposed between and separating the upper and lower foot members, being more flexible than the upper and lower foot members to allow the upper and lower foot members to have a greater stiffness and greater force response while the energy transfer medium maintains a cushion effect for absorbing impact; and

an adjustable fastener, coupling the energy transfer medium and upper and lower foot members together, to selectively tighten and loosen the upper and lower foot members to adjust stiffness of the foot.

15. A prosthetic foot in accordance with claim 14, wherein the energy transfer medium has opposite, non-parallel, upper and lower contact surfaces along which the respective upper and lower foot members track during flexion.

16. A prosthetic foot in accordance with claim 14, wherein the energy transfer medium has opposite, parallel, upper and lower contact surfaces.

17. A prosthetic foot in accordance with claim 14, wherein the energy transfer medium includes a continuous member with a double wedge configuration including a forward wedge shape disposed in a forward location and a rearward wedge shape disposed in a rearward location, the forward and rearward wedge shapes tapering towards one another.

18. A prosthetic foot in accordance with claim 14, wherein the energy transfer medium includes a middle portion and a lateral side, and wherein the energy transfer medium tapers from the middle portion to the lateral side such that the side is thinner than the middle portion to allow the upper and lower foot members to rotate about a longitudinal axis of the foot to simulate ankle rotation.

19. A prosthetic foot in accordance with claim 14, wherein the energy transfer medium is removably coupled to the upper and lower foot members such that various different energy transfer mediums with different stiffnesses may be substituted.

20. A prosthetic foot in accordance with claim 14, wherein the energy transfer medium has a stiffness which varies along a longitudinal direction.

21. A prosthetic foot in accordance with claim 14, wherein the energy transfer medium includes separate forward and rearward mediums movably disposed in respective forward and rearward locations to be selectively located along the longitudinal axis of the foot to adjust stiffness.

22. A prosthetic foot in accordance with claim 21, further comprising slots formed in the upper and lower foot members; and wherein the adjustable fasteners are movably disposed in the slots to selectively locate the mediums along the longitudinal axis of the foot.

23. A prosthetic foot in accordance with claim 21, further comprising a plurality of holes formed in the upper and lower foot members to receive the fasteners, and wherein the fasteners may be selectively located in the holes to selectively locate the mediums along the longitudinal axis of the foot.

24. A prosthetic foot in accordance with claim 14, wherein the energy transfer medium includes separate forward and rearward mediums, disposed in respective forward and rearward locations, having different stiffnesses.

25. A prosthetic foot in accordance with claim 14, further comprising:

a pivot joint pivotally connecting the upper and lower foot members and having a pivot point about which the upper and lower foot members pivot with respect to one another.

26. A prosthetic foot in accordance with claim 14, further comprising:

a secondary upper foot member, extending from the attachment location to the heel location; and

a secondary energy transfer medium, located between the secondary upper foot member and the lower foot member.

27. A prosthetic foot in accordance with claim 14, wherein the upper and lower foot members include a gap extending from the heel portion to the toe portion to split the upper and lower foot members into first and second foot members to simulate toe rotation.

28. A prosthetic foot, comprising:

an energy storing, lower foot member extending from a heel portion to a toe portion;

an energy storing, upper foot member, movably coupled to and spaced above the lower foot member, extending from an attachment portion which is configured for attachment to a stump of an amputee, through an arcuate portion, and to a coupling portion coupled to the lower foot member;

separate forward and rearward energy transfer mediums, movably disposed in respective forward and rearward locations between the upper and lower foot members, and being selectively located along a longitudinal axis of the foot to adjust stiffness; and

at lest one fastener coupling the energy transfer mediums and upper and lower foot members together.

29. A prosthetic foot in accordance with claim 28, wherein the at least one fastener includes adjustable fasteners to selectively tighten and loosen the upper and lower foot members to adjust stiffness of the foot.

30. A prosthetic foot in accordance with claim 28, wherein the forward and rearward energy transfer mediums have different stiffnesses.

31. A prosthetic foot in accordance with claim 28, wherein the energy transfer mediums have opposite, non-parallel, upper and lower contact surfaces along which the respective upper and lower foot members track during flexion.

32. A prosthetic foot in accordance with claim 28, wherein the energy transfer mediums have opposite, parallel, upper and lower contact surfaces.

33. A prosthetic foot in accordance with claim 28, wherein the energy transfer mediums have a greater flexibility than the upper and lower foot members to allow the upper and lower foot members to move with respect to one another and flex, and to provide a cushion to soften the feel of the foot while allowing the upper and lower foot members to be stiffer.

34. A prosthetic foot in accordance with claim 28, wherein each of the energy transfer mediums includes a wedge configuration.

35. A prosthetic foot in accordance with claim 28, wherein each of the energy transfer mediums includes a middle portion and a lateral side, and wherein each of the energy transfer mediums tapers from the middle portion to the lateral side such that the side is thinner than the middle portion to allow the upper and lower foot members to rotate about a longitudinal axis of the foot to simulate ankle rotation.

36. A prosthetic foot in accordance with claim 28, wherein the energy transfer mediums are removably coupled to the upper and lower foot members such that various different energy transfer mediums with different stiffnesses may be substituted.

37. A prosthetic foot in accordance with claim 28, wherein the energy transfer mediums have a stiffness which varies along a longitudinal direction.

38. A prosthetic foot in accordance with claim 28, further comprising slots formed in the upper and lower foot members; and wherein the adjustable fasteners are movably disposed in the slots to selectively locate the mediums along the longitudinal axis of the foot.

39. A prosthetic foot in accordance with claim 28, further comprising a plurality of holes formed in the upper and lower foot members to receive the at least one fastener, and wherein the at least one fastener may be selectively located in the holes to selectively locate the mediums along the longitudinal axis of the foot.

40. A prosthetic foot in accordance with claim 28, further comprising:

a pivot joint pivotally connecting the upper and lower foot members and having a pivot point about which the upper and lower foot members pivot with respect to one another.

41. A prosthetic foot in accordance with claim 28, further comprising:

a secondary upper foot member, extending from the attachment location to the heel location; and

a secondary energy transfer medium, located between the secondary upper foot member and the lower foot member.

42. A prosthetic foot in accordance with claim 28, wherein the upper and lower foot members include a gap extending from the heel portion to the toe portion to split the upper and lower foot members into first and second foot members to simulate toe rotation.

43. A prosthetic foot, comprising:

an energy storing, lower foot member extending from a heel portion to a toe portion;

an energy storing, upper foot member, movably coupled to and spaced above the lower foot member, extending from an attachment portion configured for attachment to a stump of an amputee, through an arcuate portion, and to a coupling portion coupled to the lower foot member;

an energy transfer medium, disposed between the upper and lower foot members, having a middle portion and a lateral side, the energy transfer medium tapering from the middle portion to the lateral side such that the side is thinner than the middle portion to allow the upper and lower foot members to rotate about a longitudinal axis of the foot to simulate ankle rotation; and

at least one fastener, coupling the energy transfer mediums and upper and lower foot members together.

44. A prosthetic foot in accordance with claim 43, wherein the at least one fastener includes at least one adjustable fastener to selectively tighten and loosen the upper and lower foot members to adjust stiffness of the foot.

45. A prosthetic foot in accordance with claim 43, wherein the energy transfer medium has an upper surface and a rounded upper edge between the upper surface and the lateral side.

46. A prosthetic foot in accordance with claim 43, wherein the energy transfer medium has a lower surface and rounded lower edge between the lower surface and the lateral side.

47. A prosthetic foot in accordance with claim 43, wherein the energy transfer medium has an upper surface and rounded upper edge between the upper surface and the lateral side; and wherein the energy transfer medium has a lower surface and rounded lower edge between the lower surface and the lateral side.

48. A prosthetic foot in accordance with claim 43, wherein the energy transfer medium has a greater flexibility than the upper and lower foot members to allow the upper and lower foot members to move with respect to one another and flex, and to provide a cushion to soften the feel of the foot while allowing the upper and lower foot members to be stiffer.

49. A prosthetic foot in accordance with claim 43, wherein the energy transfer medium has opposite, non-parallel, upper and lower contact surfaces along which the respective upper and lower foot members track during flexion.

50. A prosthetic foot in accordance with claim 43, wherein the energy transfer medium includes a continuous member with a double wedge configuration including a forward wedge shape disposed in a forward location and a rearward wedge shape disposed in a rearward location, the forward and rearward wedge shapes tapering towards one another.

51. A prosthetic foot in accordance with claim 43, wherein the energy transfer medium is removably coupled to the upper and lower foot members such that various different energy transfer mediums with different stiffnesses may be substituted.

52. A prosthetic foot in accordance with claim 43, wherein the energy transfer medium has a stiffness which varies along a longitudinal direction.

53. A prosthetic foot in accordance with claim 43, wherein the energy transfer medium includes separate forward and rearward mediums movably disposed in respective forward and rearward locations to be selectively located along the longitudinal axis of the foot to adjust stiffness.

54. A prosthetic foot in accordance with claim 48, further comprising slots formed in the upper and lower foot members; and wherein the adjustable fasteners are movably disposed in the slots to selectively locate the mediums along the longitudinal axis of the foot.

55. A prosthetic foot in accordance with claim 48, further comprising a plurality of holes formed in the upper and lower foot members to receive the fasteners, and wherein the fasteners may be selectively located in the holes to selectively locate the mediums along the longitudinal axis of the foot.

56. A prosthetic foot in accordance with claim 43, further comprising;

a pivot joint pivotally connecting the upper and lower foot members and having a pivot point about which the upper and lower foot members pivot with respect to one another.

57. A prosthetic foot in accordance with claim 43, further comprising:

a secondary upper foot member, extending from the attachment location to the heel location; and

a secondary energy transfer medium, located between the secondary upper foot member and the lower foot member.

58. A prosthetic foot in accordance with claim 43, wherein the upper and lower foot members include a gap extending from the heel portion to the toe portion to split the upper and lower foot members into first and second foot members to simulate toe rotation.

59. A prosthetic foot, comprising:

a substantially flat, energy storing, lower foot member formed of a flexible and resilient material which stores energy when flexed, the lower foot member extending from a heel portion to a toe portion;

an energy storing, upper foot member, movably coupled to and disposed on the lower foot member, formed of a flexible and resilient material which stores energy when flexed, the upper foot member extending from an attachment portion which is configured for attachment to a stump of an amputee, through an arcuate portion, and to a coupling portion coupled to the lower foot member;

an energy transfer medium, disposed on the upper foot member and coupled to the upper and lower foot members; and

a clip, coupling the energy transfer medium to the upper and lower foot members; and

the energy transfer medium having a greater flexibility than the upper and lower foot members to allow the upper and lower foot members to move with respect to one another and flex, and to provide a cushion to soften the feel of the foot while allowing the upper and lower foot members to be stiffer.

60. A prosthetic foot in accordance with claim 50, further including an adjustment member coupled to the clip and bearing against the energy transfer medium to selectively tighten and loosen the upper and lower foot members to adjust stiffness of the foot.

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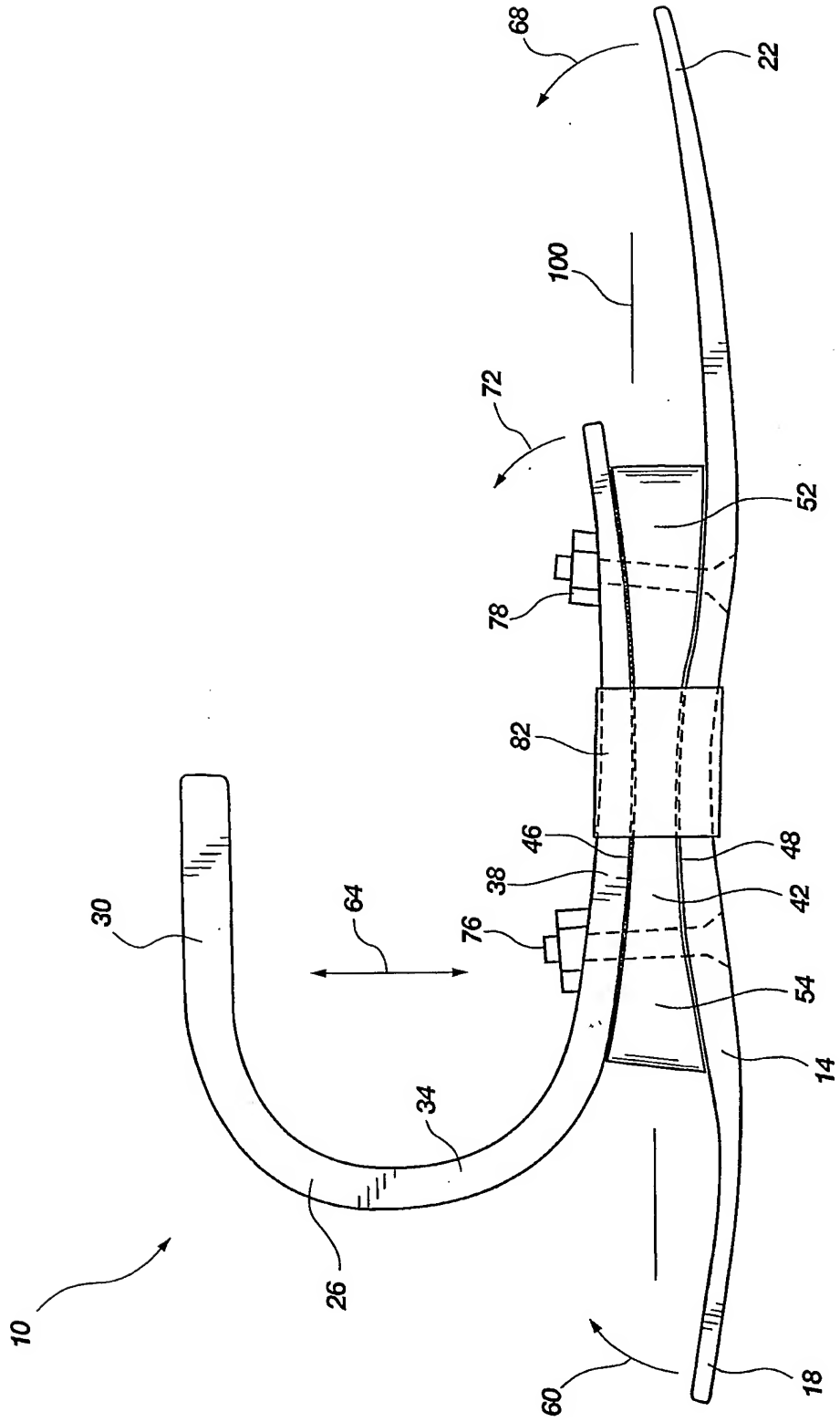

Fig. 1

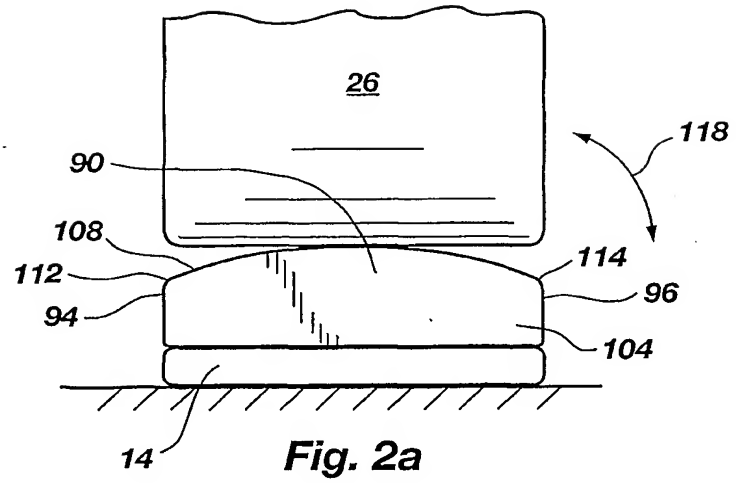

Fig. 2a

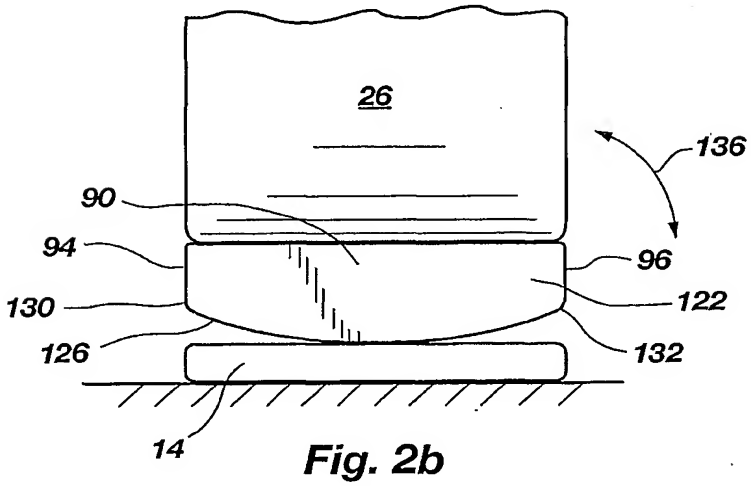

Fig. 2b

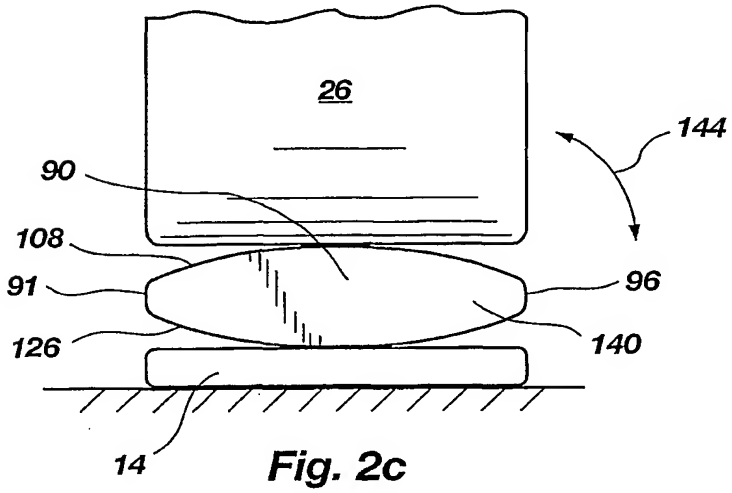

Fig. 2c

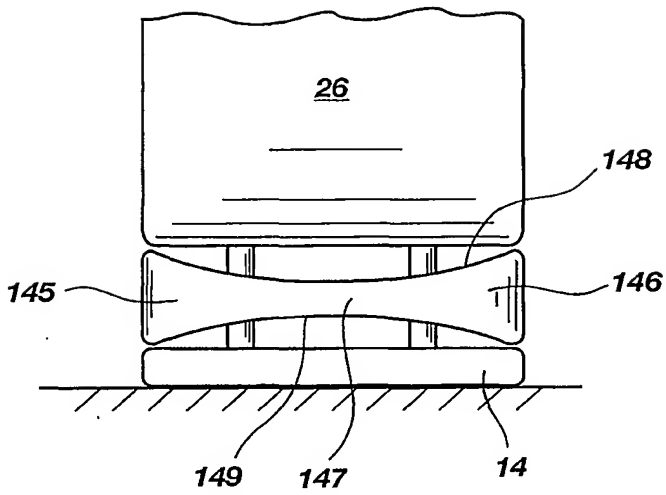

Fig. 2d

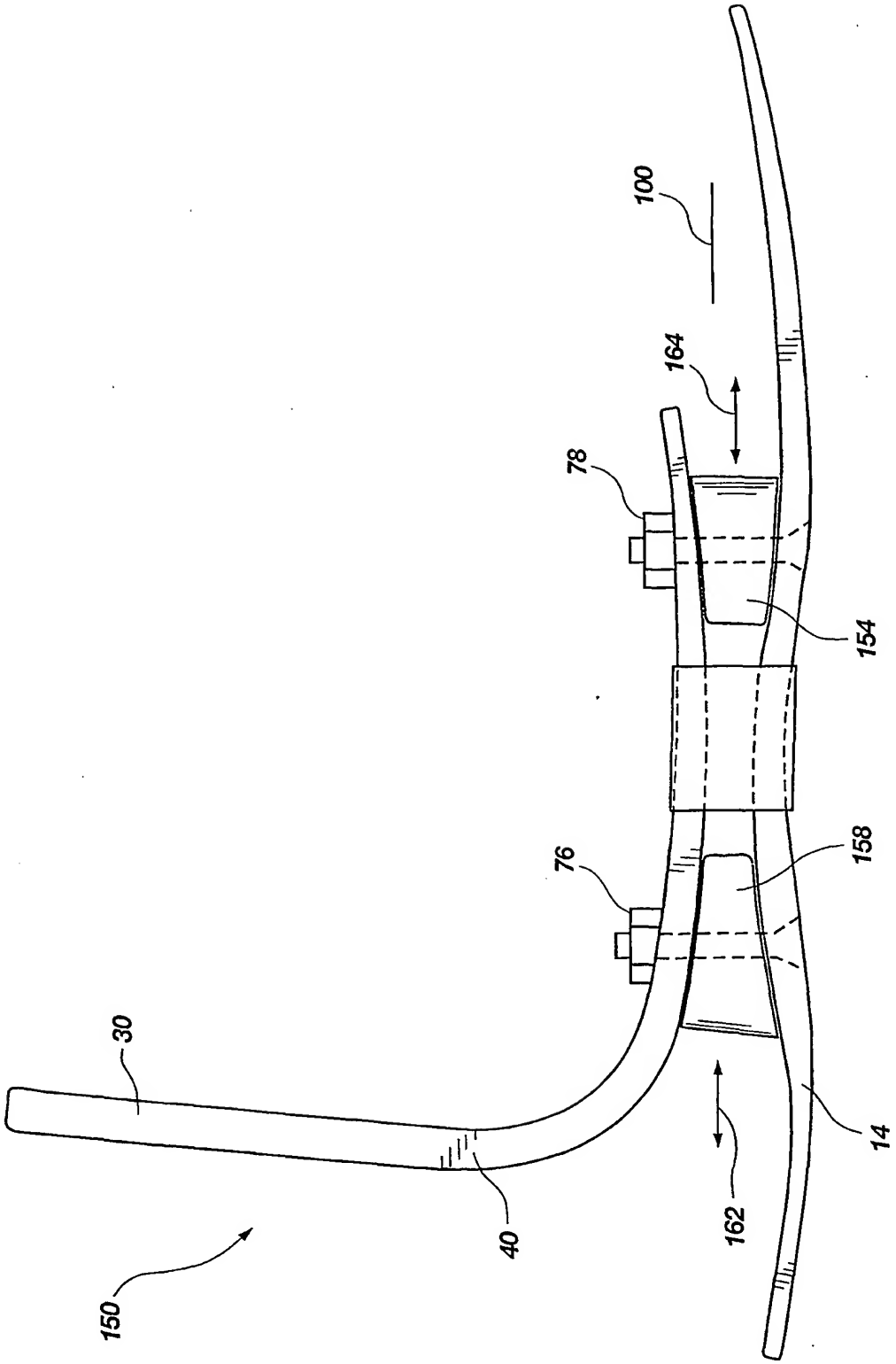

Fig. 3

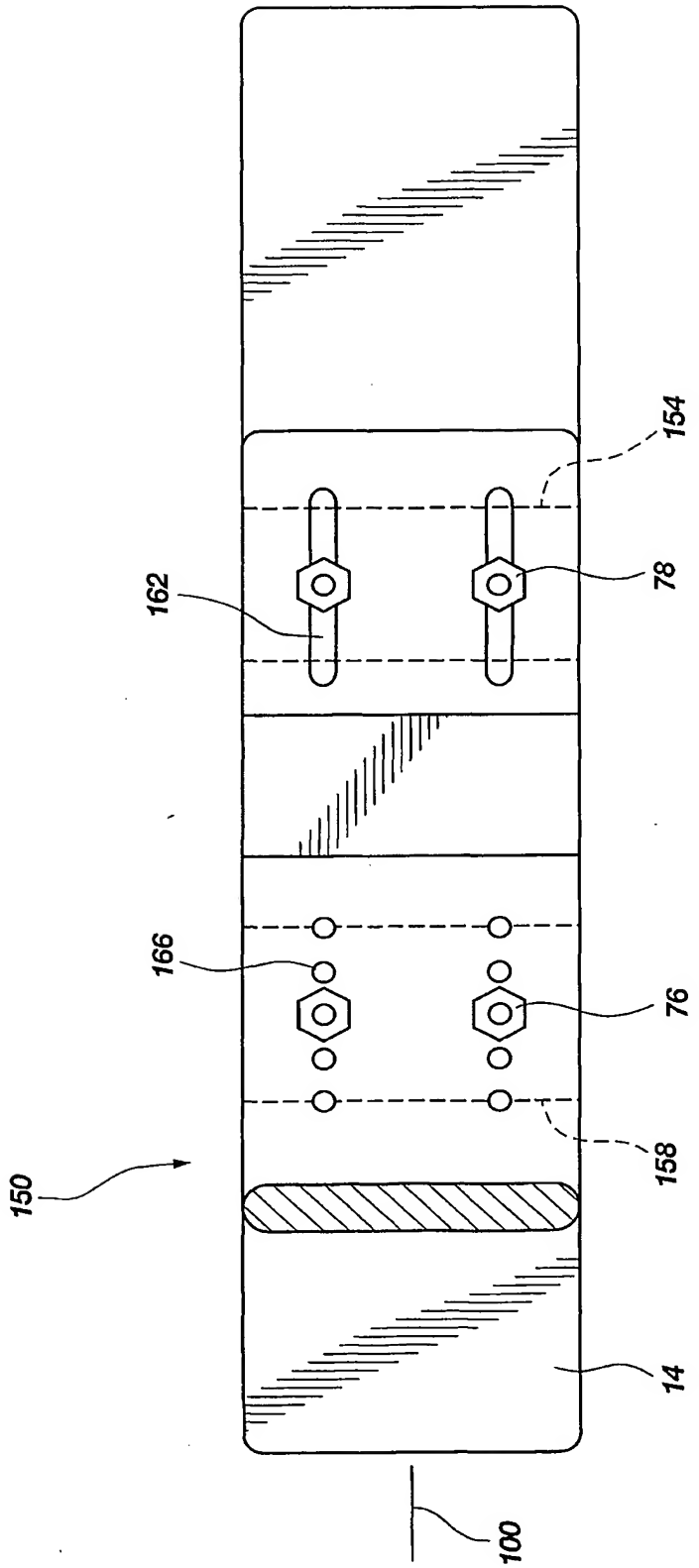

Fig. 4

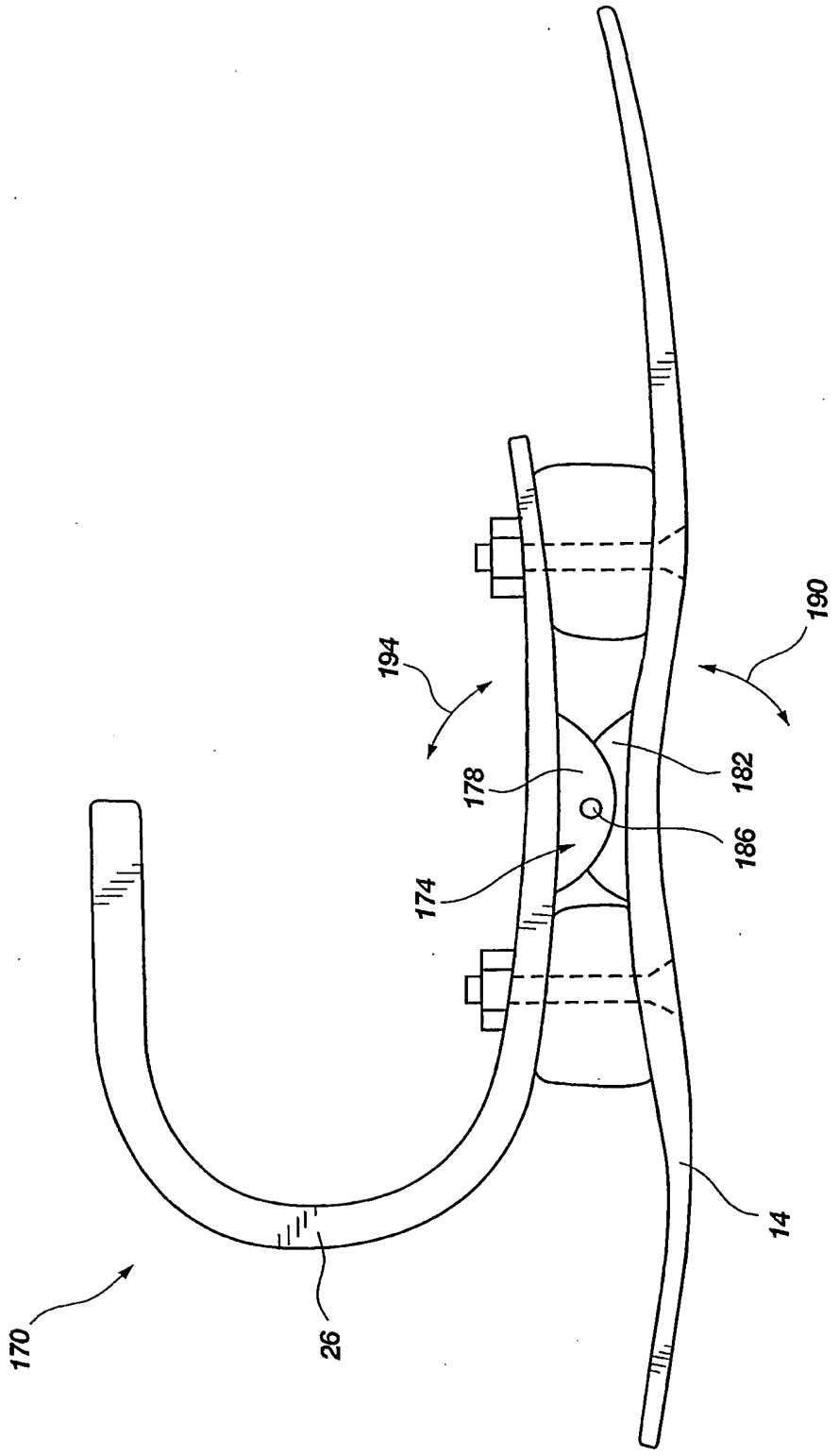

Fig. 5

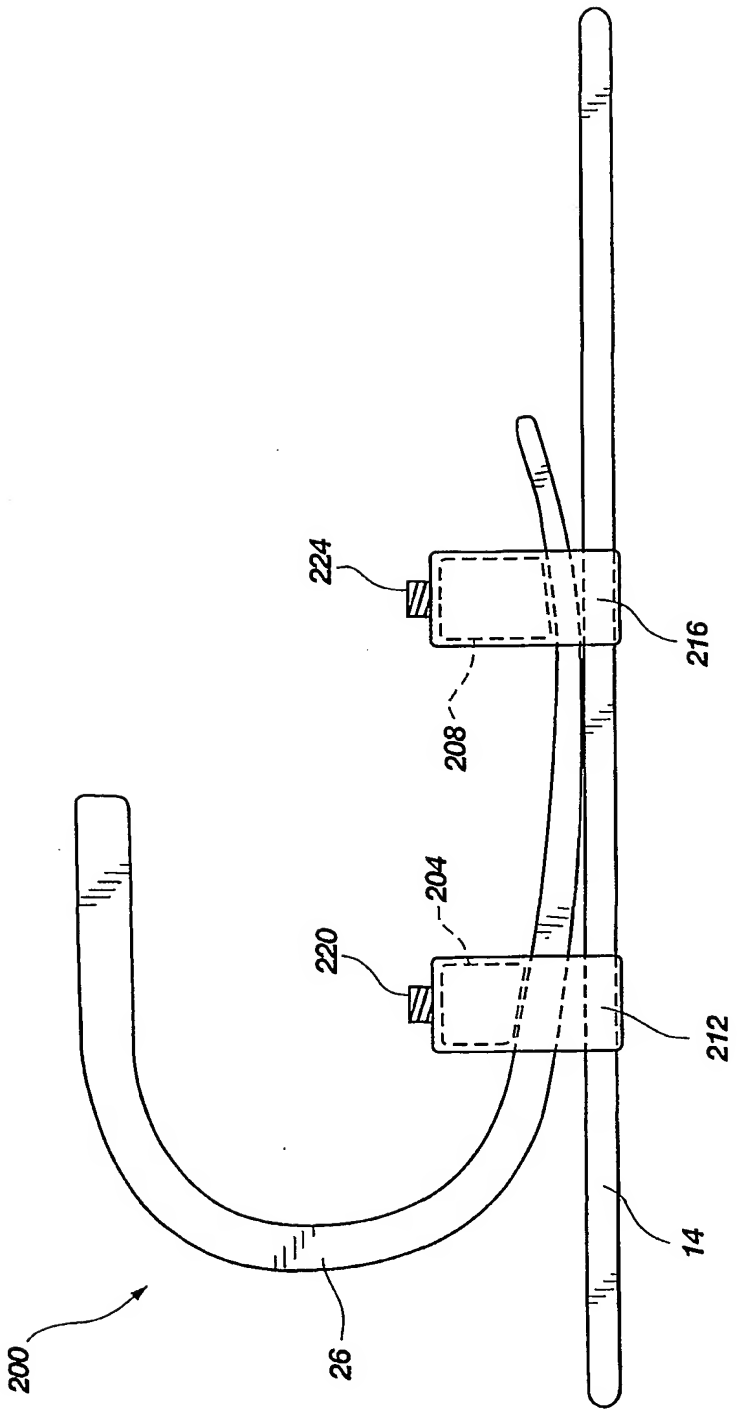

Fig. 6

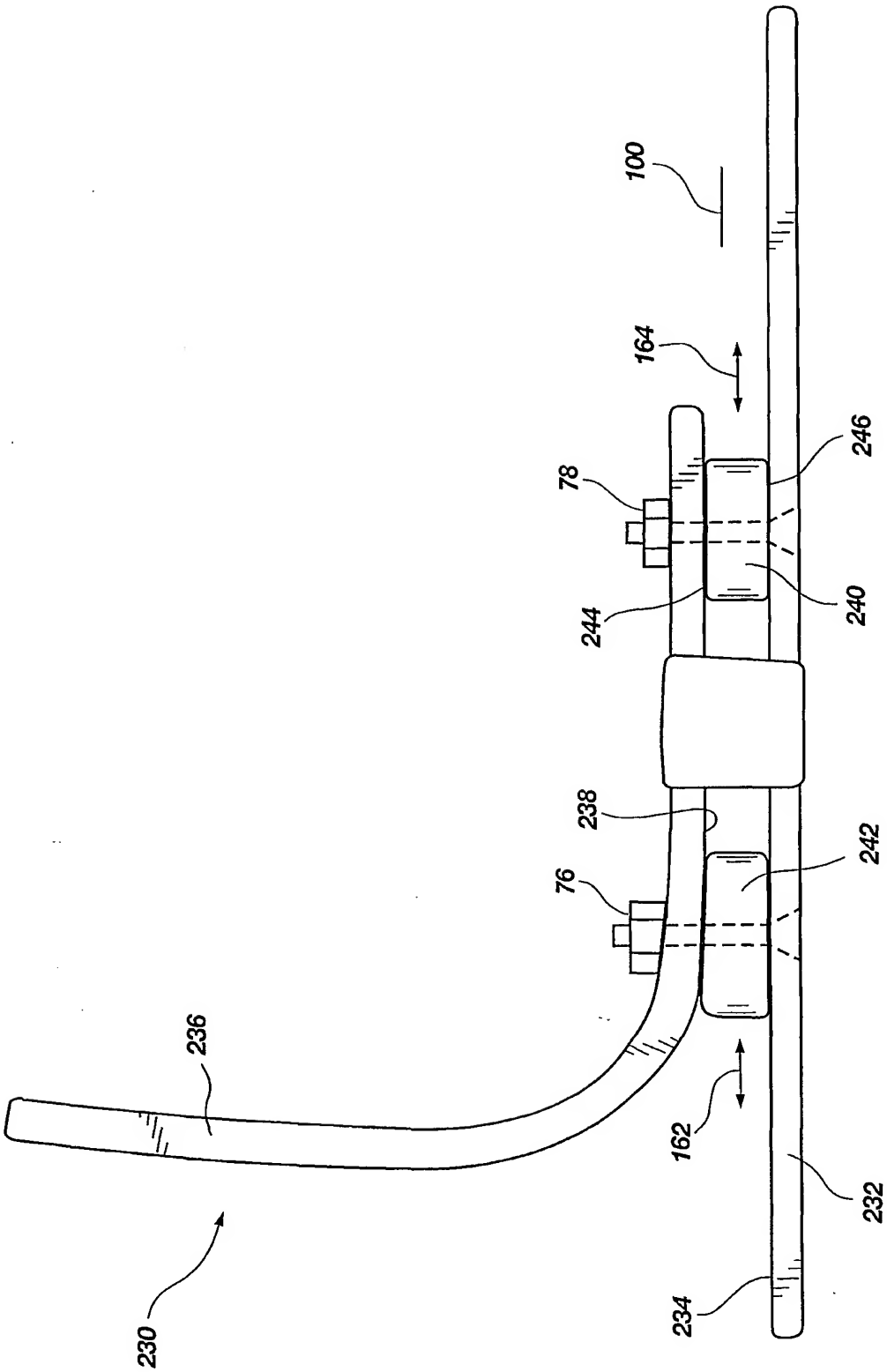

Fig. 7

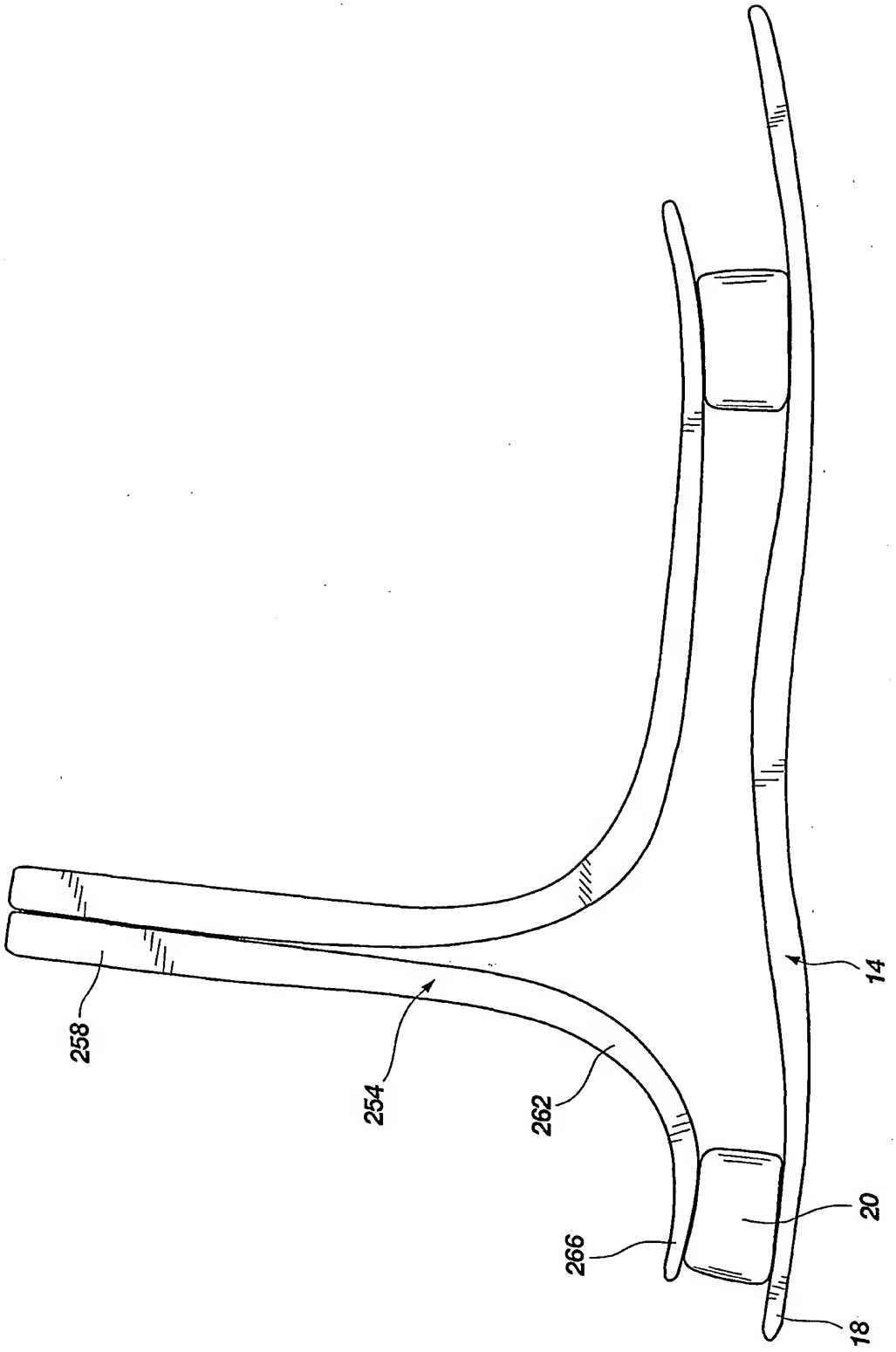

Fig. 8

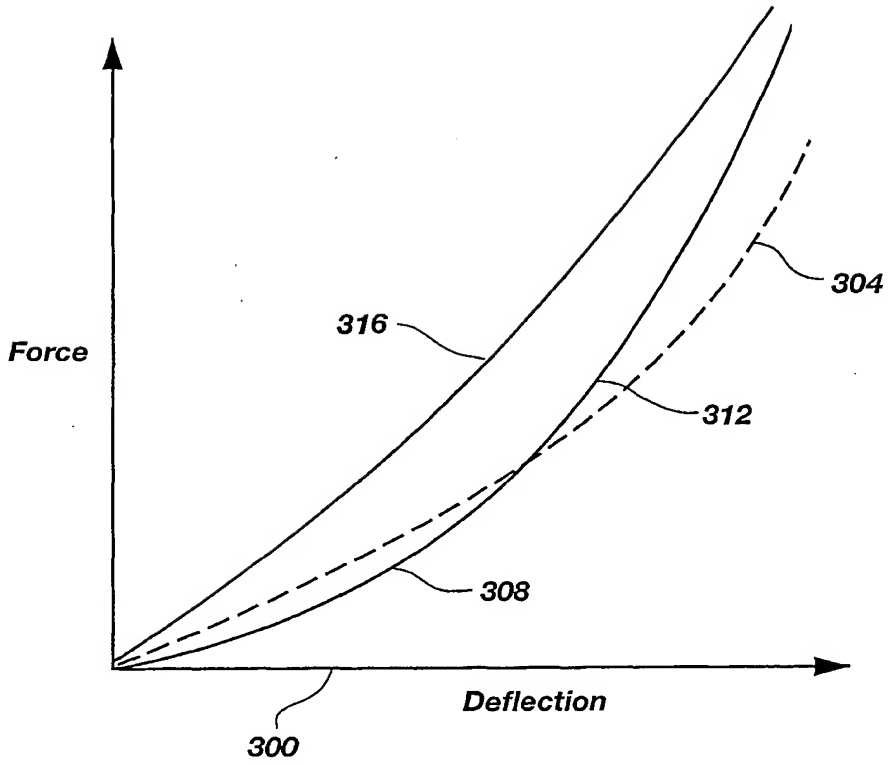

Fig. 9

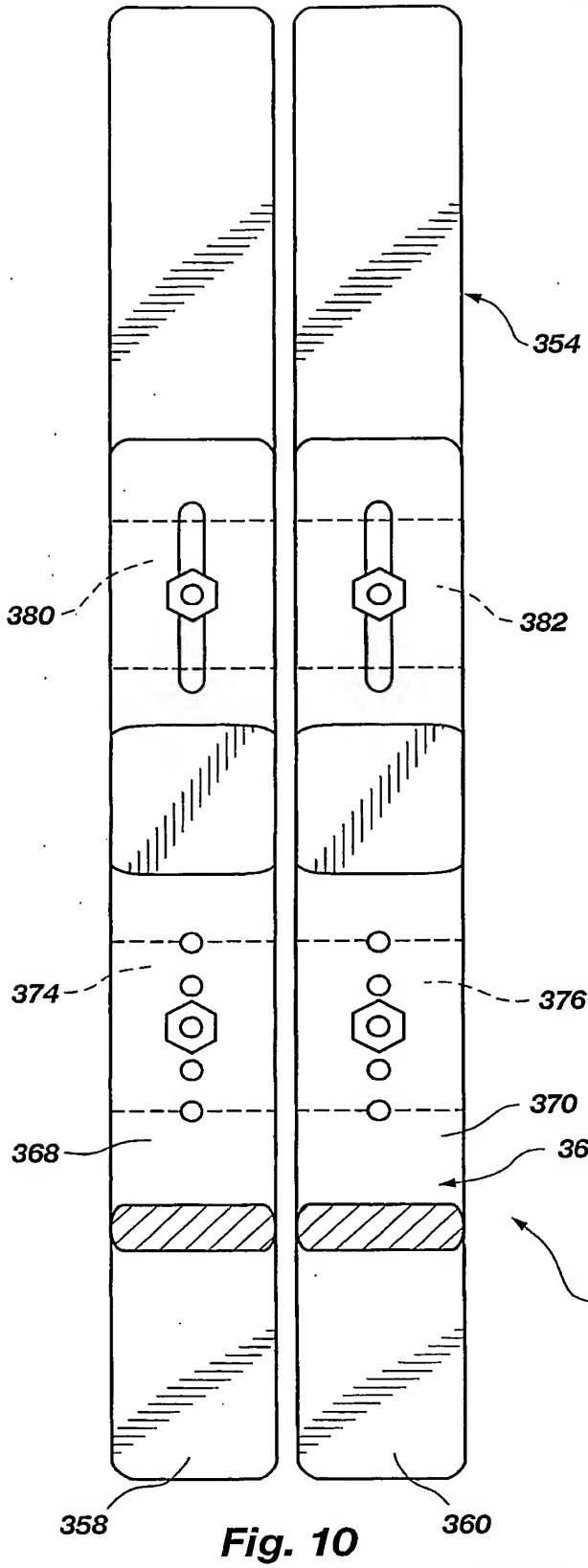
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Fig. 10

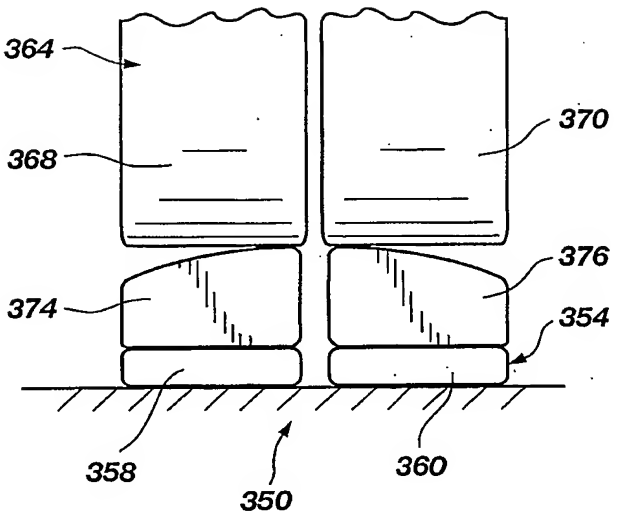
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Fig. 11